INCH - POUND
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MIL-W-8604A
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MILITARY STANDARD

FUSION WELDING FOR AEROSPACE APPLICATIONS

AMSC N/A AREA THJM

DEPARTMENT OF DEFENSE
Washington, DC 20301

Fusion Welding for Aerospace Applications

1. This MIL Standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Engineering Center, Systems Engineering and Standardization Department (SESD), Code 53, Lakehurst, NJ 08733-5100, by using the self addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

This document supersedes MIL-W-8604A, Welding, Fusion; Aluminum Alloys; Process and Performance of; MIL-W-8611A, Welding, Fusion; Steel and Corrosion and Heat Resistant Alloys; Process and Performance of; and MIL-W-18326, Welding of Magnesium Alloys, Gas and Arc, Manual and Machine Processes for. The purpose of MIL-STD-2219 is to standardize the requirements for fusion welding of metals used for the aerospace community.

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1. SCOPE

1.1 Purpose. The purpose of this document is to provide minimum requirements for weld filler materials, workmanship, inspection and record requirements for fusion welding of alloys applicable to aircraft, missiles, other aerospace equipment, their parts and accessories.

1.2 Processes. Fusion welding shall be accomplished using one of the following processes.

Flux Cored Arc Welding (FCAW)
Gas Metal Arc Welding (GMAW)
Gas Tungsten Arc Welding (GTAW)
Oxyfuel Welding (OFW)
Plasma Arc Welding (PAW)
Submerged Arc Welding (SAW)
Shielded Metal Arc Welding (SMAW)

1.3 Classification. The welds shall be of the following classes:

Class A
Class B
Class C

These classifications refer only to the levels of inspections required and to the quality standard levels applied as outlined in Section 5 and Table 5-4. Clarification of classes is given in 3.3.

1.4 Requirements and information. This document contains both mandatory requirements and guidance information. The mandatory requirements indicated by the words "shall" or "is required" are designed to serve as standards applicable to materials, workmanship, inspection, and quality control. Guidance information is indicated either by the words "should" or "may".

1.5 References within this document. References in this document to a particular paragraph or section number of this document shall include all applicable subparagraphs under that paragraph or section number. For example, a reference to paragraph 4.4 shall include subparagraphs 4.4.1, 4.4.2, 4.2.4.1, etc.

2. REFERENCE DOCUMENTS

2.1 Government documents. Unless otherwise specified, the following specifications and standards of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DODISS) specified in the solicitation form a part of this standard to the extent specified herein (see 2.4.1).

SPECIFICATIONS

FEDERAL

BB-A-106	-	Acetylene
BB-C-101	-	Carbon dioxide
BB-H-886	-	Hydrogen
BB-H-1168	-	Helium
BB-O-925	-	Oxygen
BB-N-411	-	Nitrogen

MILITARY

MIL-A-18455	-	Argon, Technical.

STANDARDS

MILITARY

MIL-STD-105	-	Sampling Procedures and Tables for Inspection by Attributes.
MIL-STD-410	-	Nondestructive Testing Personnel Qualification and Certification.
MIL-STD-453	-	Inspection, Radiographic.
MIL-STD-1595	-	Aerospace Welder Performance Qualification.
MIL-STD-1949	-	Inspection, Magnetic Particle.
MIL-STD-2154	-	Ultrasonic Inspection, Requirements for.
MIL-STD-6866	-	Inspection, Penetrant Method of.

2.2 Other documents. The following documents form a part of this standard to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted shall be those listed in the issue of the DODISS specified in the solicitation. The issues of documents which have not been adopted shall be those in effect on the date of the cited DODISS (see 2.4.2).

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM B 600 - Recommended Practice for Descaling and Cleaning Titanium and Titanium Alloy Surfaces

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19102.)

AMERICAN WELDING SOCIETY (AWS)

AWS A2.4 - Symbols for Welding and Nondestructive Testing

AWS A3.0 - Welding Terms and Definitions

AWS B2.1 - Welding Procedure and Performance Qualification

(Application for copies should be addressed to the American Welding Society, P.O. Box 351040, Miami, FL 33135.)

COMPRESSED GAS ASSOCIATION (CGA)

CGA G1.1 - Commodity Specification for Acetylene

CGA G4.3 - Commodity Specification for Oxygen

CGA G5.3 - Commodity Specification for Hydrogen

CGA G6.2 - Commodity Specification for Carbon Dioxide

CGA G9.1 - Commodity Specification for Helium

CGA G10.1 - Commodity Specification for Nitrogen

CGA G11.1 - Commodity Specification for Argon

(Application for copies should be addressed to the Compressed Gas Association,Inc., Crystal Gateway 1, Suite 501, 1235 Jefferson Davis Highway, Arlington VA 22202.)

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

AMS 2815 - Identification, Welding Wire, Line Code System

AMS 2816 - Identification, Welding Wire, Color Code, System

(Application for copies should be addressed to SAE, 400 Commonwealth Drive, Warrendale, PA 15096.)

(Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through other informational services.)

2.3 Order of precedence. In the event of a conflict between the text of this standard and the references cited herein, the text of this standard takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Acronyms. The acronyms and letter designations used in this standard are defined as follows:

DCAS	-	Defense Contract Administration Service
FCAW	-	Fluxcored Arc Welding
GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
HAZ	-	Heat-affected-zone
NDE	-	Nondestructive Examination
OFW	-	Oxyfuel Welding
PAW	-	Plasma Arc Welding
PQR	-	Procedure Qualification Record
SAW	-	Submerged Arc Welding
SMAW	-	Shielded Metal Arc Welding

3.2 General definitions. Unless otherwise defined herein, welding terms, definitions and symbols shall conform to AWS A2.4 and AWS A3.0.

3.3 Clarification of classes. In this document, the classes detail what inspections are applicable and the allowable defect limits. It is up to the cognizant engineering organization to specify the inspections required for part after an assessment of part criticality is determined. The following clarification is given for information only to assist the design activity and is not mandatory.

Class A: Critical application. A weldment is critical where a failure of any portion would cause loss of system, loss of major component, loss of control, unintentional release of critical stores, or endangering of personnel.

Class B: Semi-critical application. A weldment is semi-critical when a failure would reduce overall efficiency of the system but loss of the system or endangering of personnel would not be experienced.

Class C: Non-critical application. A weldment is non-critical where a failure would not affect the efficiency of the system or endanger personnel.

When the class is not specified in the contract or on the drawing, Class A shall apply.

3.4 Acceptable. Complies with or conforms to the applicable standard or specification.

3.5 Arc strike. Any inadvertent localized heat-affected-zone (HAZ) or change in the contour of the finished weld or adjacent base metal resulting from an arc or heat generated by the passage of electrical energy between the surface of the finished weld or base metal and a current source, such as welding electrodes or magnetic inspection prods.

[Over one linear inch, unless otherwise specified

3.6 Buttering or build-up. The deposition of filler metal on a base metal surface to restore base material or weld surface dimensions, or to interpose a layer of weld metal on the material surface of the joint prior to joining the material members together.

3.7 Cognizant engineering organization. The engineering organization responsible for the design of the welded assembly. (See 6.5)

3.8 Finished weld. Welds which have received final inspection and have been accepted.

3.9 Government representative. Any Government representative specifically authorized to approve equipment, material, or procedures within the scope of this document. They can be, but are not limited to, the following:

a. Contracting Officer
b. DCAS
c. AFPRO
d. NAVPRO

There is no priority to this list. The contract shall specifically identify the designated Government representative.

3.10 Inspector. Contractor, DCAS, and other Government representative qualified to accept or reject materials or workmanship.

3.11 Qualification. Conformance to the stated requirements of a document.

3.12 Qualified welder/welding operator. Any person who has met the requirements of MIL-STD-1595.

4. GENERAL REQUIREMENTS

4.1 General requirements. The purpose of these qualification requirements is to ensure that qualified procedures are used by properly trained and qualified personnel. It shall be the responsibility of the contractor to ensure that only qualified personnel, procedures, and nondestructive test equipment are used in fabrication and inspection necessary to comply with this document. Procedures and personnel previously qualified or approved shall not require requalification provided that qualifications are appropriate for the production welding to be done and have not lapsed, and provided that qualification records are available to substantiate prior qualification or approval.

4.2 Welding procedure qualification. Prior to engaging in production welding, the welding procedure for Classes A and B shall be qualified. The pertinent welding variables shall be identified. Section 2 of AWS B2.1 should be used as a guideline in the development of the welding procedure to ensure that all pertinent variables and tolerances are included. Requalification criteria shall be determined by the cognizant engineering organization.

4.3 Welding personnel qualification. Each welder or welding operator shall be qualified in accordance with MIL-STD-1595 prior to performing any production welding.

4.4 Welding and auxiliary equipment.

4.4.1 General. Welding equipment, such as welding machines, welding torches, regulators and filler metal feeders shall be capable of making satisfactory welds, when operated by a qualified welder or welding operator.

4.4.2 Welding apparatus capability. Where doubts about the capability of any welding apparatus to function satisfactorily exists, the equipment shall not be used until the necessary repairs, adjustments, or replacements have been made.

4.4.2.1 Furnace control equipment. Unless otherwise specified in the welding procedure documents, furnace control temperature tolerances shall be within $\pm$ 50°F.

4.4.2.2 Cooling furnaces. Cooling furnaces shall be provided with suitable means for controlling the cooling rate.

4.5 NDE procedure qualification.

4.5.1 Radiographic inspection. Qualification of radiographic inspection procedures, including film processing procedures, shall be in accordance with MIL-STD-453.

4.5.2 Ultrasonic inspection. Qualification of ultrasonic inspection procedures shall be in accordance with MIL-STD-2154.

4.5.3 Magnetic particle inspection. Qualification of magnetic particle inspection procedures shall be in accordance with MIL-STD-1949.

4.5.4 Penetrant inspection. Qualification of penetrant inspection procedures shall be in accordance with MIL-STD-6866.

4.5.5 Other nondestructive tests. Nondestructive tests, procedures, techniques, equipment and materials not specifically addressed in this document may be used if approved in the contract or by the cognizant engineering organization.

4.6 Qualification of inspection personnel.

4.6.1 Qualification of NDE personnel. Nondestructive examination personnel shall be qualified in accordance with MIL-STD-410 or other NDE standards satisfactory to the cognizant engineering organization. When the contract, purchase order or engineering drawing specifies the use of examination methods not presently incorporated in MIL-STD-410, the manufacturer shall be responsible to develop and submit for approval to the cognizant engineering organization training programs, written procedures, examinations, and practical demonstrations equivalent to those required for the other examination methods covered by MIL-STD-410 or other NDE standards. These shall establish the capability of the personnel to perform the required examinations.

4.6.2 Visual weld inspector. Personnel performing visual examinations shall be trained and qualified. Visual weld inspector qualification criteria and training shall be documented in a written procedure.

4.7 Vision test. Inspection personnel shall be required to pass an annual vision test. The test shall be conducted by a trained technician using the standard test methods for determining visual acuity. The standard of acceptance for the vision test shall be natural or corrected near distance acuity such that the individual is capable of reading J1 letters on the standard Jaeger type chart for near vision. Other equivalent visual tests may be substituted for the Jaeger Chart. Glasses or other corrective aids used to pass vision tests shall be worn when performing production work.

4.8 Requalification. Requalification of welders and welding operators shall be in accordance with MIL-STD-1595. Requalification of the weld procedures shall be as specified by the cognizant engineering organization (see 4.2). Requalification of NDE personnel shall be in accordance with MIL-STD-410.

4.9 Identification. Each welded assembly, or the documentation accompanying each welded assembly, shall be marked with the date and the signature or individually assigned stamp or code of the welder who made the weld, and with the date and signature(s) or individually assigned code or stamp of the inspector(s) who accepted the weld.

4.10 Records requirements.

4.10.1 General. Written procedures shall assign responsibility and provide accountability for performing work and inspections. Records to demonstrate compliance with this document are required.

4.10.2 Records.

4.10.2.1 General. Each contractor shall prepare and maintain written records as detailed below. Vendor inspection records or mill certificate records will fulfill the requirements of this section for that portion of the required information contained herein.

4.10.2.2 Qualification records.

4.10.2.2.1 Welding procedure qualification. These records should be as specified by AWS B2.1.

4.10.2.2.2 Welder and welding operator qualification. These records shall be as required by MIL-STD-1595.

4.10.2.2.3 NDE personnel qualification. Records of personnel qualification shall be maintained in accordance with MIL-STD-410.

4.10.2.3 NDE records.

4.10.2.3.1 Radiographic inspection. These records shall be as required by MIL-STD-453.

4.10.2.3.2 Ultrasonic inspection. These records shall be as required by MIL-STD-2154.

4.10.2.3.3 Magnetic particle inspection. These records shall be as required by MIL-STD-1949.

4.10.2.3.4 Penetrant inspection. These records shall be as required by MIL-STD-6866.

4.10.2.4 Inspection records. Each contractor shall ensure that the records, including radiographic films, compiled for his materials, components or weldments are retained for a period of five years for Class A or B welds and one year for Class C welds following acceptance of the weld. They shall be available for review by the cognizant engineering organization upon request.

4.10.2.5 Workmanship. Acceptable quality and completeness of workmanship shall be assured by a record of inspection completion as the work progresses from prefabrication through completion. The record of workmanship shall be verified by the inspector's signature or assigned code or stamp.

5. DETAIL REQUIREMENTS

5.1. Welding consumables.

5.1.1 Low hydrogen electrode storage. These covered electrodes shall be procured in hermetically sealed containers. After removal from the container, the electrodes shall be stored in an oven at a temperature to prevent moisture contamination.

5.1.1.1 Exposure. After hermetically sealed containers are opened or after electrodes are removed from drying or storage ovens, the electrode exposure before use shall not exceed the following values:

E70XX	4 hrs
E80XX	2 hrs
E90XX	1 hr
E100XX	1/2 hr
E110XX	1/2 hr
E120XX	1/2 hr

5.1.2 Bare filler metal storage. Bare welding wire and welding rod shall be stored in a clean and dry environment. Heating may be employed if necessary to prevent moisture accumulation.

5.1.3 SAW flux. This flux shall be stored in a clean and dry area. Unfused SAW flux may be reused.

5.1.4 Identification. Filler metal and flux shall be properly identified.

5.1.4.1 Covered electrodes. Each covered electrode shall have distinguishable color code, type designation, or classification number marking. If markings are destroyed or missing, electrodes shall not be used.

5.1.4.2 Bare welding wire and welding rod. Each spool or coil shall carry an identifying label and each piece of bare welding rod shall be marked. Marking shall comply with the requirements of AMS 2815, AMS 2816 or other system acceptable to the cognizant engineering organization.

5.1.4.3 SAW flux. Each container shall be labeled by type and size.

5.1.5 Gases. Gases listed in the "Specification" column of Table 5-1 shall be used unless the alternate specification is specified by the cognizant engineering organization..

5.2. Manufacturing controls.

5.2.1 Joint configuration. Joint design and dimensions shall be as specified on the drawing or in the welding procedure. The resulting weld shall meet the applicable requirements of 5.4.3 and 5.4.4.

TABLE 5-1. Gases (minimum requirements).

Gases	Specifications	Alternate Specifications
Argon	MIL-A-18455	CGA G-11.1
Helium	BB-H-1168	CGA G-9.1
Oxygen	BB-O-925, Type I or II	CGA G-4.3
Nitrogen	BB-N-411, Type I or II, Class 1, Grade B	CGA G-10.1
Hydrogen	BB-H-886, Type I or II	CGA G-5.3
Acetylene	BB-A-106, Grade B	CGA G-1.1
Carbon Dioxide	BB-C-101, Grade B	CGA G-6.2
Gas Mixtures	The purity of the gases in the mixture shall be as specified for the individual gases listed above	

5.2.2 Preweld joint preparation.

5.2.2.1 Surface finish of fusion faces. Surface finish of fusion faces for Class A welds shall be defined in the welding procedure or on the drawing. Fusion faces shall be free of cracks, laminations and burrs.

5.2.2.2 Joint and filler metal cleanliness. All faying surfaces shall be free from slag, visible surface oxides, scale, protective finishes, oils, grease, dirt, and other foreign materials. Solvent cleaning is allowed for degreasing base metal and bare filler metal. Caution: Chlorinated hydrocarbon solvents shall not be used in pre-weld cleaning of titanium parts. Wire brushing, chemical cleaning, filing or scraping may be used as required to remove oxide or other contaminants from the fusion faces and faying surfaces. The cleaned area shall not be contaminated. Only clean lint-free gloves shall be used when handling cleaned titanium filler metal and joint surfaces.

5.2.3 Pre-weld joint fit-up. If not stated on the engineering drawing or in the weld procedure, joint fit-up for all classes of welds shall conform to Table 5-2 and Figures 5.1, 5.2 and 5.3, as applicable. Where a specified fit-up gap is given as part of a weld procedure and no tolerances are given, the allowances of Table 5-2 may be added. Magnesium butt joints welded from one side only may be back beveled, as shown in Figure 5-4.

TABLE 5-2. Maximum root opening.

PROCESS	OFW, SMAW GTAW, GMAW, PAW Manual	GTAW, GMAW, PAW, FCAW Machine
MAXIMUM ROOT OPENING	1/2 "T" or 0.060 inch Whichever is less	1/4 "T" or 0.030 inch Whichever is less

Where "T" is thickness of the thinner member.

5.3 Welding requirements.

5.3.1 Identification. Each welder/welding operator shall identify his work by interim marking, adjacent to the weld joint or by marking the sign-off sheet of 4.9. The interim identification shall remain adjacent to or with the weld until final weld inspection.

5.3.2 Qualified weld settings. Qualified weld settings established in accordance with Section 4 are required for machine welding of Class A welds. Qualified weld settings are not required for machine welding of Class B or C welds. Allowable variations from the established weld settings are acceptable if within $\pm$ 10%. If meter readings are used, the variation shall be based on the mean reading. Weld settings for manual welding are not required to be qualified.

5.3.3 Reproducibility of qualified machine weld settings.

5.3.3.1 When a sample is required. A sample shall be made to demonstrate the reproducibility of the machine weld settings whenever one of the following situations occur:

a. A change in the location of the welding equipment.
b. A change in the welding power supply.
c. The installation of electrical components which would affect welding parameters.
d. A change in tooling which will affect heat dissipation rate from the weld area of the joint or which will affect the shielding gas effectiveness.

5.3.3.2 Sample preparation. The reproducibility sample shall consist of a simulated or actual production joint (if production joint will be less than 10 inches in length) or 10 inches of a simulated or actual joint (where the production item requires at least a 10 inch long weld). The repoducibility sample shall meet the quality requirements of the production item.

5.3.4 Requalification of machine weld settings. Requalification of the affected machine settings shall be required when:

a. The machine settings reproducibility sample is not able to meet the requirements of this document.
b. The qualified weld settings will not provide acceptable product weld quality.

5.3.5 Welding procedures.

5.3.5.1 Filler metal. The filler metal alloy shall be specified on the drawing or in the weld procedure.

5.3.5.2 Preheating, interpass temperature control and postheating. Preheating, interpass temperature control and postheating when used in conjunction with a qualified setting shall become a part of the qualified weld setting procedure. Preheating, interpass temperature control and postheating is required for in-process correction, when it is required for the original weld. Torch heating with a gentle, soot-free, neutral flame is allowed. Oxy-acetylene torch heating is not allowed for titanium or magnesium. Localized heating is allowed. Temperature gradients shall be wide spread. The preheat, interpass and postheat temperatures specified herein apply to the weld joint area. Maximum temperatures apply to the entire part. The use of furnaces, heat lamps, resistance elements, induction heating and other devices with pyrometric controls is preferred over torch heating.

5.3.5.2.1 Magnesium castings. Preheating and interpass temperature control is recommended as follows:

a. F condition - 450° to 500°F
b. T condition - 250° to 300°F

Recommended for sections greater than 0.125 inch thick.

5.3.5.2.2 Steels. Preheating and interpass temperature control should be exercised with steels that are susceptable to cracking. Some examples of steels which are susceptable to cracking are:

1040	4137	4335	4340	8635	8740	AMS 6407
4135	4140	4335M	4340M	8735	4330M	

5.3.5 2.3 Other base metals. Preheat and interpass temperature control is optional for all other base metals not identified in 5.3.5.2.1 and 5.3.5.2.2. If preheat and interpass temperature control are required, they shall be authorized by the cognizant engineering organization and detailed on the drawing.

5.3.5.3 Tackwelds. If filler metal is used for tacking, use the same filler metal alloy as specified for the weld. The length and size of tack welds shall be limited to a size that will be melted by the subsequent weld pass.

5.3.5.4 Fixtures. Fixtures, backing materials and hold-down bars shall be kept clean and free of contaminants during use.

5.3.5.5 Weld start and run-off tabs. Weld start and run-off tabs when used shall be composed of the same alloy as the detail parts, and shall be welded with the same filler metal as required by the part.

5.3.5.6 Weld shielding for GTAW, GMAW, and PAW. The weld shall be protected from oxidation during welding. Completed weldments including heat affected surfaces shall comply with the requirements of 5.3.5.8 and 5.4.4. Shielding gas and material combinations shall be as noted in below, unless otherwise specified in the contract or on the drawing.

Material	Gas 1/						
	Argon	Helium	Argon Helium	Argon 2/ Oxygen	Argon Hydrogen	Nitrogen	Carbon Dioxide
Aluminum	A	A	A				
Cobalt	A	A	A		A		
Copper	A	A	A				
Magnesium	A	A	A				
Nickel	A	A	A				
CRES Steels	A	A	A	A		Backing only	
Plain Carbon Steels	A	A	A	A			3/
Low alloy Steels	A	A	A	A			
Titanium	A	A	A				

A = Allowed
1/ Gas compositions and mixtures shall comply with Table 5-1.
2/ 8 percent Oxygen maximum.
3/ Only permitted on plain carbon steel with a maximum of 0.25 percent nominal carbon.

5.3.5.7 Cleaning between welds. Prior to depositing each pass of a noncontinuous multipass weld or deposition of a root pass on the side opposite the original weld, the welder or welding operator shall visually examine for contamination and defects. Contamination and defects, other than discoloration for titanium alloys, shall be removed by wire brushing, machining, rotary filing, drilling, grinding, sanding or scouring. Removal of unacceptable discoloration for titanium alloys, as specified in 5.4.4.3, shall be accomplished by any of the following methods: scraping, scouring, machining, rotary filing, wire brushing or by cleaning in accordance with ASTM B600. Cleaning titanium with chlorinated solvents or methyl alcohol is prohibited.

5.3.5.8 Post weld cleaning. Except as noted in 5.4.4.3 and 5.4.4.4, completed weldments shall be free of visible oxides, flux, spatter, scale, slag, or other foreign matter. Cleaning, if required, shall be in accordance with 5.2.2.2. Welding flux shall be completely removed by appropriate methods. Removal of material during the cleaning operation shall not exceed the allowed tolerances of the end product specification.

5.3.6 Stress relief. When required, stress relief of weldments shall be specified in the welding procedure or the drawing.

5.4 Inspection and acceptance criteria.

5.4.1 General. All welds shall be 100% visually inspected by a qualified inspector.

5.4.2 Nondestructive inspection.

5.4.2.1 Penetrant inspection. All Class A and B welds shall be inspected in accordance with MIL-STD-6866, unless magnetic particle inspection is performed. Class C weld shall be inspected when specified on the drawing or in the contract.

5.4.2.2 Magnetic particle inspection. All Class A and B welds of ferromagnetic materials shall be inspected in accordance with MIL-STD-1949 unless penetrant inspection is performed. Class C welds shall be inspected when specified on the drawing or in the contract.

5.4.2.3 Radiographic inspection. All Class A groove welds (except for fillet welds) or butt joints shall be inspected in accordance with MIL-STD-453. Class B and C welds shall be inspected radiographically per MIL-STD-453 when specified on the drawing or in the contract. Ultrasonic inspection (see 5.4.2.4) may be used in lieu of radiographic inspection when specified on the drawing or in the contract.

5.4.2.4 Ultrasonic inspection. Ultrasonic inspection in accordance with MIL-STD-2154 shall be performed when specified on the drawing or in the contract.

5.4.2.5 Extent of inspection. Unless otherwise specified in 5.4.2.1, 5.4.2.2, or 5.4.2.3, nondestructive inspection shall be performed within the following parameters to ensure that the requirements of 5.4.4 are met:

a. Class B welds - MIL-STD-105, limiting quality of 10% defective for a probability of 10% (see Table VI-a of MIL-STD-105).
b. Class C welds - no requirements.

5.4.3 Weld configuration.

5.4.3.1 Weld reinforcement and weld width. Weld reinforcement shall fair smoothly with itself and the base metal. When machine welding is required by drawing callout weld reinforcement "R" for Class A groove welds shall not exceed the limits of 1/3 T or 0.030 inch, whichever is the greater, for material thicknesses 0.375 inches and under. For material greater than 0.375 inches the maximum reinforcement shall be 0.125 inch. When machine welding is not required by drawing callout, requirement for weld reinforcement "R" for Class A weld shall not exceed the limits as follows:

a. For material up to 0.125 inch thick - 1 T maximum.
b. For material 0.125 inch to 0.510 inch thick - 1/3 T or 0.100 inch whichever is greater.
c. For material 0.510 inch and thicker - 0.170 inch maximum.

Typical examples of weld reinforcement profiles are indicated in Figure 5-5. Width of each bead of a single or multi-pass weld shall not exceed 0.625 inches for GTAW, GMAW, FCAW, SAW and PAW. For SMAW width of weave bead shall not exceed 2-1/2 times the core diameter of electrode being used.

5.4.3.2 Weld penetration. Groove welds in joints welded from only one side without a backing strip shall show complete joint penetration as evidenced by the absence of a joint line on the other side which exceeds the discontinuity limit for incomplete penetration in Table 5-4.(See Figure 5-6a). The backing strip, when required, shall be penetrated so as to ensure complete joint penetration and fusion of the root edges of the joint.(see Figure 5-6b).

5.4.3.3 Melt-through. Where the welding symbol requires full penetration, overlap, flare, flange or corner joints shall be melted down so that complete joint penetration is obtained, and the resulting weld shows no evidence that the details were joggled, flared or flanged. Typical overlap, flare, edge-flange, and corner welds are shown in Figure 5-7.

5.4.3.4 Two and three piece tee joints. Melt-thru weld dimensions for two and three piece tee joints are as shown in Figure 5-8.

5.4.3.5 Fillet welds. Fillet weld size shall be as specified in the drawing and represents the minimum weld size.

5.4.4 Weld quality.

5.4.4.1 General. Cracks, incomplete fusion and overlap, are not acceptable in any class of weld. Two or more adjacent surface discontinuities shall be treated as one when the space between them is less than the dimension of the smallest discontinuity. The dimension of any discontinuity shall be defined by its largest dimension. Interconnecting discontinuities shall be considered as a single discontinuity. Limits of discontinuity when specified in terms of percentage of thickness "T" shall be based on thinner member of the joints. In the case of weldments with variations in cross section along the joint, "T" shall be considered to be the minimum thickness at the specific discontinuity location. Arc strikes, arc burns from loose electrical connections and gouge

marks on the base metal of the finished weldment are unacceptable for Class A and B welds. Welds made from one side only under 0.125 inch thick may have the root surface faired in by using a cosmetic weld pass or by grinding, provided that complete penetration was obtained in the original weld. Preferential arc erosion of the heat affected zone on aluminum welds may be removed by lightly sanding or wire brushing followed by etching as specified in MIL-STD-6866 prior to inspection.

5.4.4.2 Discontinuity limits. Discontinuities shall not exceed the limits of Table 5-4.

TABLE 5-3. Minimum fillet weld sizes.

Material Thickness "T"	Weld Bead Size "S" 1/		Material Thickness "T"	Weld Bead Size "S" 1/	
	Double side 2/	Single side 3/		Double side 2/	Single side 3/
0.010 - 0.025	0.02	0.04	0.126 - 0.156	0.12	0.23
0.026 - 0.050	0.04	0.075	0.157 - 0.188	0.14	0.28
0.051 - 0.078	0.06	0.12	0.189 - 0.250	0.19	0.38
0.079 - 0.090	0.07	0.14	0.251 - 0.500	0.38	0.75
0.091 - 0.125	0.09	0.19			

1/ Weld bead size is determined by the thinner member.
2/ Double side welds are welds made on both sides of the joint.
3/ Single side welds are welds made from only one side of the joint.

5.4.4.3 Discoloration of titanium. Contamination resulting in discoloration of weld bead and the adjacent area is not acceptable except as follows:

a. For welds of all classes including HAZ, bright silver color is acceptable.

b. For Class A welds including zones up to 0.030 inches beyond the weld edges, silver to light straw color is acceptable but must be removed if additional welding is performed. Violet to blue or gray color contamination shall be cause for rejection of the weldment.

c. For Class B and Class C welds including zones out to 0.030 inches beyond the weld edges, silver to violet color is acceptable but must be removed if additional welding is performed. Blue color contamination is not acceptable if additional welding is performed. Blue color contamination is acceptable for the finished weld but must be removed. Gray color comtamination shall be cause for rejection of the weldment.

d. Discoloration, except for gray color, is allowed in the base metal beyond the 0.030 limit, except that blue discoloration shall be removed.
e. Removal of superficial discoloration shall be in accordance with 5.3.5.8.
f. Gray color comtamination shall be cause for rejection unless it can be conclusively proven that embrittlement has not occurred, such as by microhardness test or other direct tests.

5.4.4.4 Discoloration of 300-series corrosion resistant steel and carbon and low alloy steels. Tightly adhering iridescent temper films and light straw/tan discoloration on the finished weldment shall not be cause for rejection.

5.4.5 Disposition of unacceptable welds. Welds not meeting the requirements of 5.4.3 and 5.4.4 shall be rejected or in-process corrected as specified below. Imperfections that will be removed by subsequent machining shall not be cause for rejection. Removal of unacceptable weld metal is allowed provided the weld size and minimum base metal thickness requirements are met.

5.4.5.1 Rejections. Any defective weldment which has gone through a subsequent manufacturing operation that affects the metallurgical characteristics (other than tempering or stress relieving of martensitic steels) or that cannot be rewelded without affecting final metallurgical or surface coating characteristics shall be referred to the Material Review Board. Any weldment with cracks in the base metal shall be rejected.

5.4.5.2 In-process correction. In-process correction is any corrective action taken by the welder prior to the weldment departing the welding shop and prior to any inspection. The in-process correction history shall be part of the paperwork accompanying the weld. Rewelding shall be accomplished by the same process and filler material used to make the original weld. Manual GTAW process may be used at shop option for all processes. Corrected welds shall meet the requirements of the original welds.

5.4.5.2.1 For Class A welds. Surface and subsurface imperfections within the weld metal area (not extending into the HAZ or base metal) may be repaired one time as defined below:

a. Weld undercut, underfill or craters may be corrected by depositing a weld bead fairing in the original weld and the base metal.
b. Cracks, porosity, lack of fusion and inclusions shall be removed from the original weld prior to rewelding, except that if complete penetration can be obtained in thin sections, cracks, porosity and lack of fusion may be rewelded without removal.

c. Unacceptable overlap, weld drop-through and other protruding imperfections may be removed by dressing the weld deposit.

If a satisfactory correction is not achieved by the first repair, the weldment shall be referred to the Material Review Board.

5.4.5.4 Class B welds. Weld imperfections as defined in 5.4.5.2.1 may be repaired twice. If a satisfactory weld is not achieved by the second repair, the weldment shall be referred to the Material Review Board.

5.4.5.5 Class C welds. Repairs may be made by manufacturing as required to meet the quality requirements of Class C welds. Records are not required.

TABLE 5-4. Discontinuity limits.

IMPERFECTION	CLASS OF WELDS		
	A	B	C
SURFACE POROSITY:			
Individual size maximum	0.25 T or 0.030 inch whichever is less	0.33 T or 0.060 inch whichever is less	0.50 T or 0.090 inch whichever is less
Spacing - minimum	8 times the size of the larger adjacent imperfection	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection
Accumulated length in any 3 inches of weld - maximum	1 T or 0.12 inch whichever is less	1.33 T or 0.24 inch whichever is less	2 T or 0.36 inch whichever is less
UNDERCUT:			
For full length of weld -maximum depth	0.002 inch	0.015 T or 0.002 inch whichever is greater	0.025 T or 0.002 inch whichever is greater
Individual defect maximum depth	0.07 T or 0.030 inch whichever is less	0.10 T or 0.050 inch whichever is less	0.20 T or 0.070 inch whichever is less
Accumulated length in any 3 inches of weld - maximum	0.20 inch	0.60 inch	1.00 inch
UNDERFILL AND/OR CONCAVITY:			
For full length of weld - maximum depth	0.005 inch	0.015 T or 0.005 inch whichever is greater	0.025 T or 0.005 inch whichever is greater
Individual defect maximum depth	0.07 T or 0.030 inch whichever is less	0.10 T or 0.050 inch whichever is less	0.20 T or 0.070 inch whichever is less
Accumulated length in any 3 inches of weld - maximum	0.20 inch	0.60 inch	1.00 inch
SUBSURFACE POROSITY AND INCLUSIONS:			
Individual size maximum	0.33 T or 0.060 inch whichever is less	0.50 T or 0.090 inch whichever is less	Not applicable
Spacing - minimum	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection	Not applicable
Accumulated length in any 3 inches of weld - maximum	1.33 T or 0.24 inch whichever is less	2 T or 0.36 inch whichever is less	Not applicable
INCOMPLETE PENETRATION:			
Maximum depth	0.20 T or 0.03 inch whichever is less	0.20 T or 0.05 inch whichever is less	0.20 T or 0.05 inch whichever is less
CRATERS:			
Maximum depth	0.20 T or 0.03 inch whichever is less	0.20 T or 0.05 inch whichever is less	0.20 T or 0.05 inch whichever is less
Maximum length	1 T	1 T	2 T
CRACKS:	None	None	None
COLD SHUT: 1/	1 T or 0.1 inch 2/ Whichever is lesser	1 T maximum length	2 T maximum length

NOTES:
1/ If the defects exhibit sharp radii, sharp termination, or are cracklike, they shall be removed by grinding. If the depression is not larger than permitted, they need not be rewelded.

2/ Where possible to determine, by metal removal, the depth of cold shut shall not cause joint thichness to be less than the thinner material being welded.

6. NOTES

6.1 Subject term (keyword) listing.

Aerospace
Aluminum
Base metal
Cobalt base alloys
Electrodes
Filler metal
Flux
Inspections
Nickel base alloys
Nondestructive examinations
Radiography
Rods and wire
Steel
Titanium
Ultrasonic
Welders
Welding
Welding operators
Welding rod
Welding wire

6.2 Clarification and cross reference of classes. Classes in this standard do not directly equate to the class definitions given in MIL-W-8604A. The classes contained in this document are clarified in 3.3.

6.3 Supersession data. This standard includes and upgrades the requirements of MIL-W-8604A dated 15 March 1982, MIL-W-8611A dated 24 July 1957, and MIL-W-18326A dated 14 June 1956. It is to be used for all new aerospace welding after the date of issue. However, any existing contracts referencing one of the above documents shall continue to use that document until such time as an agreement is reached between the procuring activity and the contractor.

6.4 Welding safety. Fumes generated during welding certain metals, in particular magnesium, present a health hazard. ANSI Z49.1 should be reviewed regarding welding safety precautions.

6.5 Cognizant engineering organization. The cognizant engineering organization is defined in 3.7 as the engineering organization responsible for the design of the welded assembly. This definition does not limit the cognizant engineering organization to the design personnel but should include the appropriate engineering personnel in the organization's material and process group, stress analysis group, welding shop and quality control as appropriate to the particular weldment.

6.5.1 Examples. The following examples are provided to add clarity.

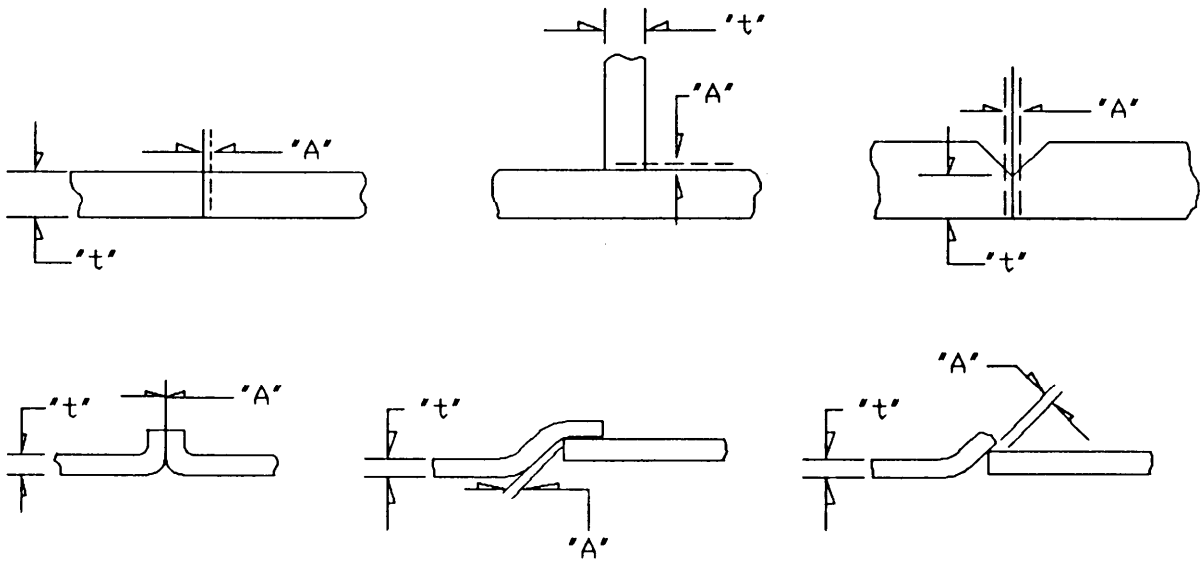
a. Company ABC is the design organization for a weldment. Welding is performed both in house and at a subcontractor. Any deviations from the design of the weldment must be approved by the cognizant engineering personnel in company ABC.
b. The Government is purchasing a weldment from company XYZ and has generated the design. Whether the welding is performed by XYZ or a subcontractor to XYZ, the cognizant engineering organization is the Government.
c. The Government has been purchasing a weldment from company ABC using a design generated by company ABC. The Government wishes to use a second source for the weldment. The Government is the cognizant engineering organization for the second source; while company ABC is also the cognizant engineering organization with respect to its in house welding shop or its subcontractors.

Custodians:
Army - AV
Navy - AS
Air Force - 11

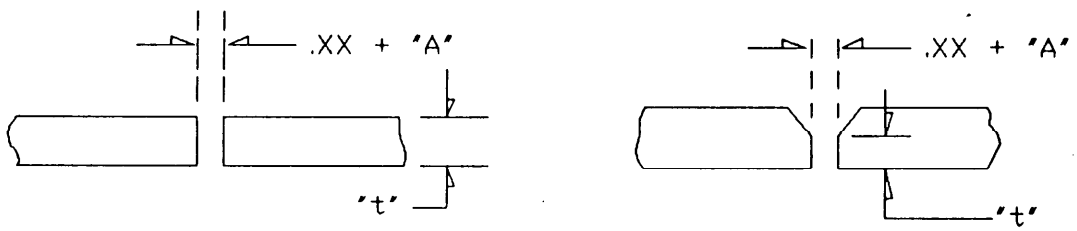
Review activities:
Army - MI, MR
Air Force - 70, 71, 82, 84, 99

Preparing activity:
Navy - AS

(Project No. THJM-0117)

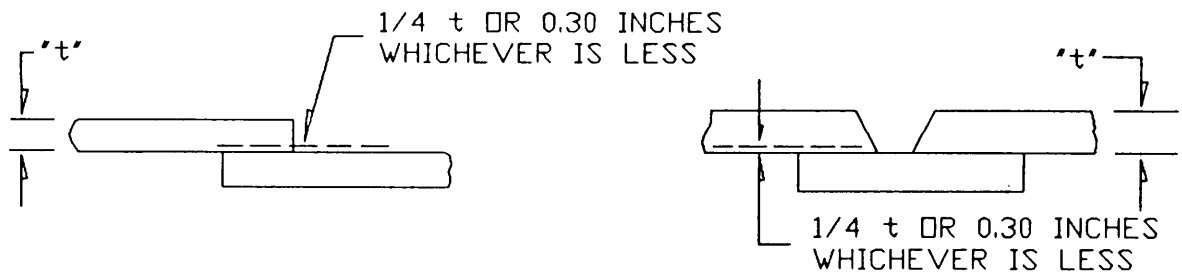


NO ROOT OPENING (METAL TO METAL FIT)



SPECIFIC ROOT OPENING (.XX) AS SPECIFIED ON THE DRAWING

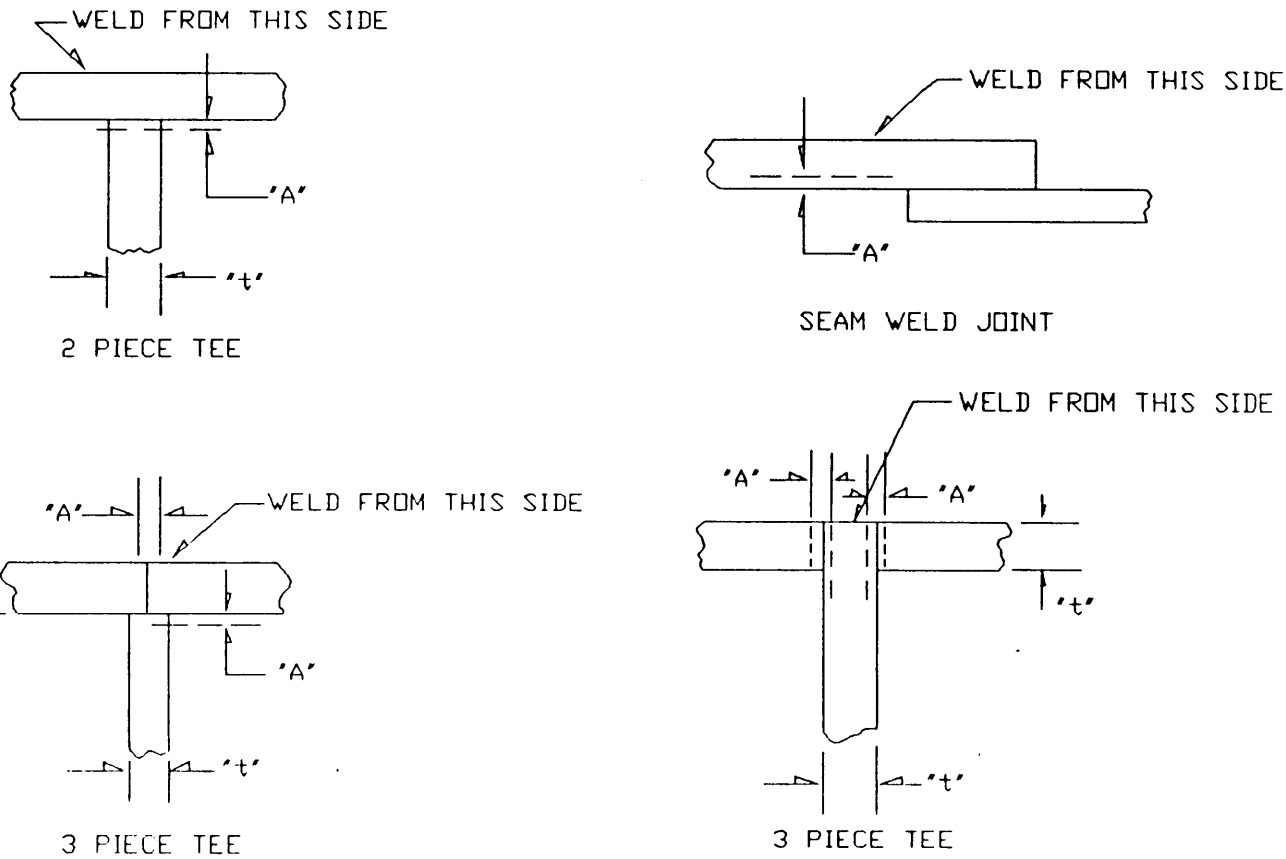
FIGURE 5-1 VARIATIONS OF ROOT OPENINGS



LAP JOINT

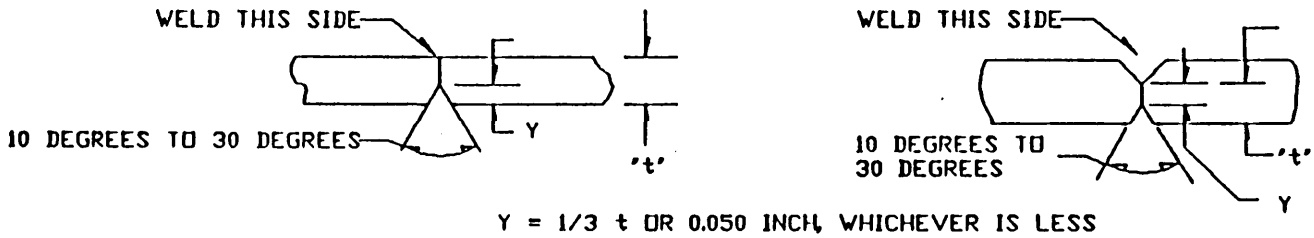
BACKING STRIP

FIGURE 5-2 ALLOWABLE SEPERATION



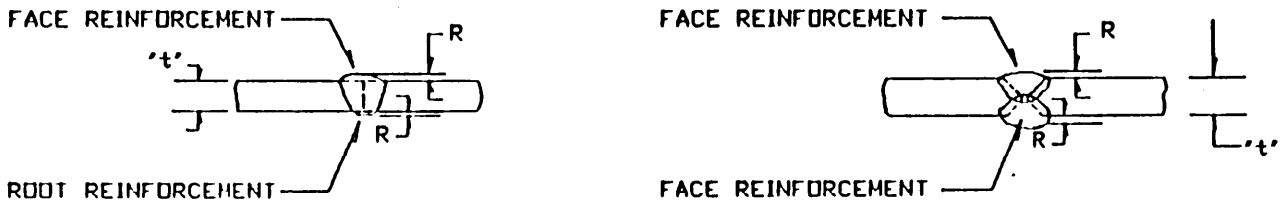
'A' = MAXIMUM ROOT OPENING
't' = THICKNESS OF BASE METAL

FIGURE 5-3 TWO AND THREE PIECE TEE AND SEAM WELD JOINTS



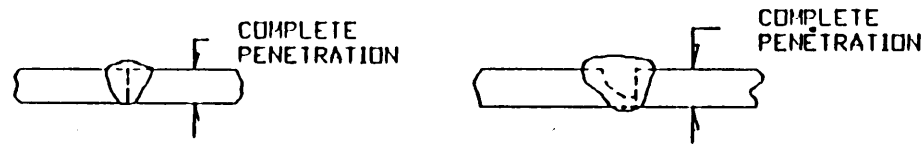
Y = 1/3 t OR 0.050 INCH, WHICHEVER IS LESS

FIGURE 5 - 4 BACK BEVELING MAGNESIUM

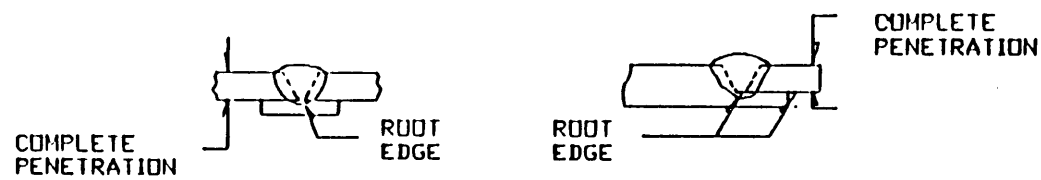


R = WELD REINFORCEMENT

FIGURE 5-5 WELD REINFORCEMENT PROFILES



(a) WELDED FROM ONE SIDE WITHOUT BACKING STRIP



(b) WELDED FROM ONE SIDE WITH BACKING STRIP

FIGURE 5-6 PENETRATION PROFILES

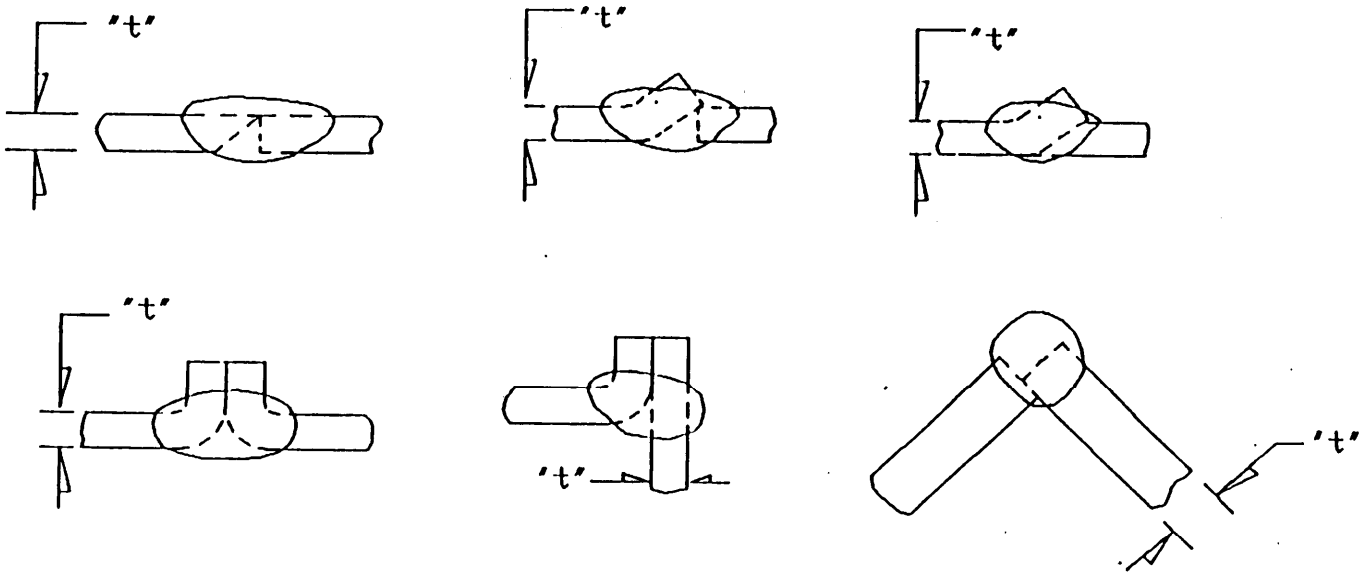
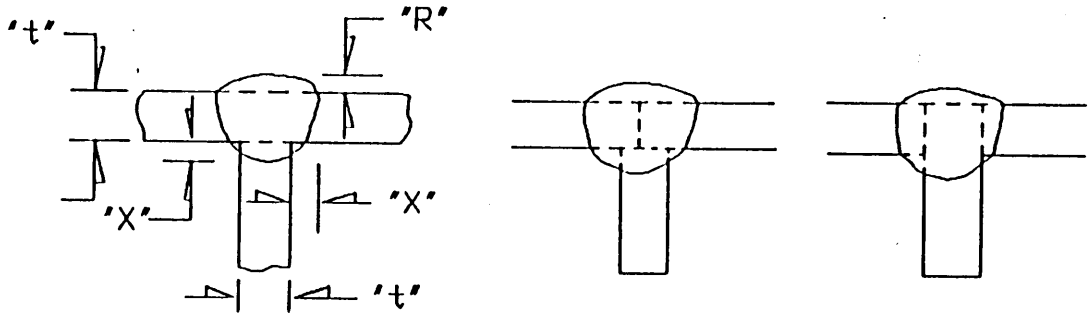


FIGURE 5-7 MELT THROUGH WELDS



t = THICKNESS OF THINNER MEMBER

(DIMENSIONS ARE TYPICAL)

a. MINIMUM 'x' DIMENSIONS ARE 1/2 t OR 0.015 INCH, WHICHEVER IS GREATER.
b. MAXIMUM 'x' DIMENSIONS ARE 2 1/2 t OR 0.187 INCH, WHICHEVER IS LESS.
c. WELD REINFORCEMENT 'R' FOR CLASS A WELDS SHALL BE IN ACCORDANCE WITH 5.4.3.3.

FIGURE 5-8 MELT THROUGH TEE JOINTS

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	☐ VENDOR ☐ USER ☐ MANUFACTURER ☐ OTHER *(Specify)*: _____
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